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MINERALS AND ROCKS

furnished to California schools by the California Division of Mines and Geology

by Salem J. Rice

1962
Special Publication 33

This publication was prepared to accompany the sets of minerals and rocks sent by the Division to California schools. One copy is supplied free with each set. Additional copies of this publication are available for 50 cents each, or 30 cents each in orders of 10 or more. This price, of course, does not include additional sets of specimens, for these are not for sale by the Division.

Special Publication 33

1962

STATE OF CALIFORNIA

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THE RESOURCES AGENCY

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CONTENTS

Silky chrysotile asbestos from Lake County.

Introduction

For many years the Division of Mines and Geology has furnished sets of California minerals and rocks to schools in the state. Originally these sets were assembled from specimens to be discarded from the Division's petrographic laboratory, and were sent to all schools requesting them. The demand was so slight that some rather rare specimen material (such as gold in quartz) was included in them. The sets were informally assembled with little effort, and neither time nor money was budgeted by the Division for this service.

In the decade following World War II, California's population boom, combined with an awakening of interest in the teaching of science, resulted in such an increase in demand for the sets that the Division's facilities to provide them were severely taxed. Some of the rarer specimens required for these old sets were difficult to obtain in quantity, so of necessity the sizes of the specimens were reduced and the distribution of sets limited to elementary schools.

The collection accompanied by this description is different from those previously distributed by the Division. None of the minerals and rocks in it are rare in California, although some of them are rare in certain areas of the state. The object of the set is to familiarize students with many of the common rocks that make up the bulk of the earth's crust * in this region. These common rocks are the host for local accumulations of rarer valuable or otherwise interesting minerals, some of which are also represented by specimens in the collection.

* The outer solid layer of the earth is known as the crust. It ranges in thickness from about 4 miles beneath the deep ocean floor to as much as 30 miles beneath the surfaces of the continents, and rests on a more dense layer called the mantle. Thus, the crust is thicker beneath the continents than beneath the oceans.

How to Enlarge School Collections

California is one of the most complex geological areas in the world. Even a highly generalized geological map, such as figure 1, indicates something of the structural complexity of the earth's crust here, and suggests that rocks characteristic of one area in the state might be rare or lacking in another. Therefore it is impractical, in the scope of a single collection such as this one, to represent adequately the rocks of all areas.

It is suggested that schools can add to this collection in order to build displays representative of their local geological settings. This can be done by having teachers or students collect appropriate specimens from the vicinity of the schools. The specimens can be identified by local geologists or by the laboratory of the Division of Mines and Geology.

Such specimens should be carefully collected and numbered, and notes made regarding location and other pertinent information (such as, "layered rock from roadcut", "vein in rock", "beach pebble", etc.). If specimens are to be identified by the Division laboratory, duplicate specimens of each rock type should be collected and given the same number (small pieces of adhesive tape may be used for temporary labelling). Then one of each set of duplicate specimens can be forwarded for identification to the Laboratory, Division of Mines and Geology, Ferry Building, San Francisco 11. A laboratory report will be returned identifying each specimen submitted, but will have no meaning to the sender if an identical specimen, identically numbered, is not retained by him. (A note of caution is appropriate here: if students are to collect the specimens, they should be assigned different number sequences so that numerous different specimens submitted will not have the same number.)

The laboratory services of the Division are free to citizens of California, but they are limited to identification of two specimens per person per month. A letter of instructions stating the information desired and the approximate locality from which the material was collected should be submitted with specimens, preferably attached to the package. Specimens are not returned by the laboratory unless requested, in which case return postage must be supplied by the sender.

Specimens that are to be placed in the collection should be given permanent numbers. This is necessary in order to insure against confusion of specimens if temporary labels are lost. For this purpose, a spot of white enamel can be put on each specimen, and the appropriate collection number printed on this spot with India ink. This number should correspond with that on a card containing the identification and other pertinent information regarding the specimen.

CLASSIFICATION AND IDENTIFICATION OF MINERALS AND ROCKS

Minerals

To the geologist, minerals are the "building blocks" of the earth's crust, for in combinations or aggregates they make up the rocks. Each mineral has reasonably precise characteristics by which it can be distinguished from other minerals. But the term "mineral" is sometimes loosely used, so its meaning in the geological sciences needs to be defined for our purposes. To a geologist a substance must have the following characteristics to be called a mineral:

1. It must occur naturally and be inorganic.
2. It must have a chemical composition and physical properties that are either fixed or that vary only slightly within definite limits.
3. It must have a charcteristic internal structure (called *crystal lattice*) determined by a fixed and orderly arrangement of the atoms within it.

The minerals are the naturally occurring chemicals of the earth. All substances are composed of the tiny particles called atoms, of which there are some 96 different types (called elements) in our natural world. Individual atoms cannot be observed directly, so the things we see are composed of combinations of very large numbers of atoms. Only rarely do atoms of a single element make up a substance; most commonly two or more different kinds of atoms occur in precise combinations, or molecules (called chemical compounds by the chemist).

Molecules have different properties than the elements of which they are made. For example, table salt (the mineral *halite*) is a brittle white substance composed of equal amounts of two elements, sodium and chlorine, the atoms of each being nicely arranged in an alternating manner within the cubic lattice structure of the salt molecule. If we were to break down the molecular structure of salt to separate the sodium and chlorine, we would find that in the pure state sodium is a soft, silvery-white metal, and chlorine is a greenish gas. Whereas salt is edible, both sodium and chlorine are toxic or poisonous when pure (neither element is found pure in nature). Therefore, the things we see around us largely owe their chemical and physical characteristics to the properties of the chemical compounds that compose them, and not to the individual properties of the elements present in them.

There are many hundreds of thousands of different chemical compounds known to us, most of them part of the organic world (the living things) or manufactured by men. Only a few thousand compounds, most of them rare, occur naturally in the inorganic crust of the earth, and these are the minerals.

A chemical formula is given in the description of each mineral in the set. These formulas indicate the basic relative proportions of the elements present in the minerals. For example, the formula for *pyrite* (FeS_2) indicates that this mineral is made up of iron (Fe) and sulfur (S) in the exact proportions of one iron atom for every two sulfur atoms.

Minerals are classified according to their chemical compositions and lattice characteristics, but the determination of these properties requires considerable training and laboratory facilities. Fortunately, differences in these characteristics give the different minerals rather distinct properties that can easily be observed, and that can be used to distinguish them one from another. The following comments discuss some of the characteristics of these properties of minerals, and methods of observing them.

1. *Color*—Some minerals have a single characteristic color, while others may have a considerable range in color.

The true colors of many minerals, particularly the light-colored ones, can be so easily masked by stains, tarnish, or impurities that one should be very careful in observing this characteristic. For example, clay is a white mineral that is a major constituent of soils; but the white color of clay is seldom seen because of the presence of strong coloring agents such as brown iron oxide and black organic material.

While determining the color of a mineral, one should also observe whether it is transparent, translucent, or opaque to the transmission of light.

2. *Luster*—The way a mineral reflects light, or shines, is called luster. Terms used to describe this property are mostly self-explanatory; thus minerals may appear metallic, sub-metallic (almost metallic), vitreous (glassy), resinous, greasy, pearly, silky, or adamantine (gem-like). A fresh surface is desirable in most cases to observe the true luster of a mineral.

3. *Hardness*—The hardness of a mineral is a measure of the ease with which it can be scratched. There are all grades of hardness among minerals, from those like talc, that can be scratched with

the finger nail, to diamond, the hardest natural substance known. Mineralogists have established a scale of hardness from 1 to 10, with certain minerals representing the whole-number values within the scale. These are:

1. talc	6. orthoclase (a type of feldspar)
2. gypsum	7. quartz
3. calcite	8. topaz
4. fluorite	9. corundum
5. apatite	10. diamond

Each mineral on the scale will scratch any other with a lower number.

Even without a set of these minerals for testing, the hardness of most minerals can be estimated with the aid of common implements or materials. Thus, the finger nail has a hardness slightly more than 2, a penny is about 3, a steel knife blade is about 5, window glass is about 5½, and a steel file is about 6½.

Hardness should not be confused with properties like brittleness and toughness. For example, quartz can be shattered almost as easily as glass, but will scratch the hardest steel. On the other hand, talc forms tough masses that do not fracture easily, but they can be scratched with the finger nail.

4. *Streak*—The streak of a mineral is the color of its powder. It is most easily observed by rubbing the mineral on a piece of white unglazed porcelain (called a streak plate), but can also be observed by fine crushing of a specimen with a hammer.

Although all white minerals have white or colorless streaks, many colored and black minerals have streaks that are entirely different from the color of the mineral. The streak is often more dependable than the apparent color of a specimen, because minor impurities that commonly change the normal color of a mineral do not affect the streak color.

5. *Cleavage*—Cleavage is the tendency of a mineral to break along one or more flat planes, and is controlled by the lattice structure of the mineral. Minerals may have none, one, two, or more cleavage directions, but the number characteristic of a mineral species is constant for all specimens of that mineral. Examples of these in the set are: quartz, that has no readily observable cleavage but fractures along curved surfaces; mica, that has one cleavage direction and breaks into flat sheets or flakes; hornblende (the dark mineral in the gabbro specimen), that has two cleavage directions and breaks into long, thin fragments; and calcite, that has three cleavage directions to yield rhombohedral fragments when fractured.

6. *Specific gravity*—This is the ratio of the weight of a specimen to that of an equal volume of water. Thus if the weight of a mineral specimen is three times that of the volume of water it displaces, its specific gravity is 3.

With practice in hefting hand specimens of various known specific gravities, one can learn to estimate specific gravities of unknown materials with useful accuracy. To illustrate this, it is suggested that the calcite and barite specimens in the set be hefted for comparison. (For mineralogical purposes, hefting is the process of holding a specimen in the hand and estimating its weight relative to that of another specimen of known specific gravity and of approximately the same size. One often does this to judge if a letter weighs more than an ounce.)

7. *Crystal forms*—Crystal faces are rarely identifiable on specimens picked up in the field, but they are sometimes diagnostic when present. Like cleavage, they are controlled by the lattice structure of minerals. Although an adequate treatment of crystallography is beyond the scope of this brief discussion, much can be learned of the nature of crystal lattices, and the resulting possible crystal faces, by constructing models and actually growing crystals. Procedures for making these experiments are outlined in the book "Crystals and Crystal Growing", by Holden and Singer, and this as well as other books listed in the references are recommended for some interesting reading on the subject of crystals.

Information obtained by careful observation of as many of these properties as possible can be used with mineral identification tables (see references) to identify most of the minerals commonly picked up. One should be sure, however, that he is observing a single mineral fragment or aggregate, and not a rock consisting of a fine-grained aggregate of two or more different minerals. Observation of fine-grained specimens is greatly improved by the use of a 10-power magnifying lens (the "hand lens" of the geologist and botanist).

Rocks

Rocks are the geological units that occur in masses sufficiently large to be mapped, and it is by means of geological maps that we are able to interpret much of the history and structure of the earth's crust.

The great majority of rocks are composed of aggregates of mineral grains, most commonly of two or more mineral species. A few rock types, notably coal (organic) and obsidian (non-crystalline) are composed of substances that are not minerals. Being essentially mixtures of materials without definite internal arrangements of these constituents, rocks are less precisely defined than minerals.

The rocks we see at the surface of the earth may conveniently be classified into three broadly defined groups, called *igneous*, *sedimentary*, and *metamorphic* rocks. They may be further subdivided under these group headings into fine-grained, medium-grained, and coarse-grained types. For purposes of the descriptions given here, fine-grained rocks are those in which most of the individual mineral grains cannot be seen without the aid of a microscope. Medium-grained rocks are those largely made up of mineral grains visible with the unaided eye, but less than about $\frac{1}{16}$ inch in diameter; and rocks with a larger predominant grain size are called coarse grained.

1. **Igneous rocks** are those formed by cooling and solidification of molten rock, or magma. Numerous places within the crust of the earth have been (and some are now) subjected to partial or complete melting of the rock at depths of 10 or 20 miles. In places some of the resulting magma rose along fissures to be erupted at the surface by means of the various phenomena of volcanic activity. Some gradually cooled and solidified near the depth of melting, a process requiring much time because of the insulating effect of the overlying rocks. According to the times required for cooling at different depths, any magma may yield rocks that differ rather widely in appearance, although they have similar chemical compositions.

Magma that solidifies at great depth normally cools so slowly that the resulting rocks are coarse grained—composed of mineral grains that are $\frac{1}{10}$ to $\frac{1}{2}$ inch or more in size. These are called *plutonic igneous rocks*, and can become exposed at the surface only by the great uplift and erosion that accompanies mountain building. In contrast, the *volcanic igneous rocks* result when magma solidifies rapidly at very shallow depths or is erupted at the surface. Magma erupted as a lava flow cools very rapidly, so that there is little time for crystals to grow before the flow solidifies. The resulting volcanic rocks are very fine grained or glassy, but in places they contain scattered large crystals of minerals that had begun to crystallize in the magma before eruption. Many volcanic rocks contain spherical or ellipsodial cavities caused by gas bubbles that were trapped in the magma at the time of solidification.

Magmas differ in chemical composition from place to place, yielding rocks composed of different mineral assemblages. As a result, the classification of igneous rocks is based largely on two criteria, chemical composition (approximately revealed by the mineral assemblage), and grain size of the constitutent minerals.

A magma rich in the elements silicon and potassium, but poor in sodium, iron, and magnesium, may yield *granite or granodiorite* (coarse-grained, light-colored rocks) where it cools at great depth; it may yield *rhyolite* or *dacite* (very fine-grained, generally light-colored rocks) where erupted at or near the surface; or it may form *obsidian* (gray or black volcanic glass) where erupted at the surface and cooled very quickly. These rocks are similar in bulk chemical composition, but quite different in appearance.

Another magma, relatively poor in silicon and potassium, but richer in sodium, iron, and magnesium, may yield *gabbro* (coarse-grained, dark colored rock) if it cools at depth, or *basalt* (very fine-grained, dark-gray or black rocks) where it is erupted as lava flows.

Magmas intermediate between these in bulk chemical composition yield plutonic rocks such as *diorite* and *syenite*, and their relatively common volcanic equivalents *andesite* and *trachyte*.

Violent volcanic eruption of any of these magmas may yield light-colored, loosely consolidated deposits of *tuff*, or "volcanic ash", composed of finely divided volcanic glass shards and mineral grains.

The predominant minerals in igneous rocks are *feldspars* (mostly white or pink); *quartz* (white or clear); *muscovite* (white or clear); and the black minerals *biotite*, *hornblende*, and *augite*. Thus the geologists' field identification of an igneous rock is determined by these minerals; which of them are present, in what proportion, and in what grain size.

Right. Alternating beds of black shale and buff sandstone at Point San Pedro, San Mateo County. *Photo by C. W. Jennings and R. G. Strand.*

2. **Sedimentary rocks** are those composed of mineral and organic debris transported and deposited by mechanical or chemical means on the surface of the lithosphere (the solid portion of the earth). For the most part, this debris consists of the mineral grains and rock fragments loosened by weathering of the surface rocks and transported mechanically by streams and rivers to basins of deposition.

When deposited, buried by succeeding deposits, and consolidated or cemented, the mechanically transported materials become the detrital sedimentary rocks. They are broadly classified according to the predominant size of fragments within any given bed. Such rocks made up of very small particles, principally clay, are called *mudstone* when massive, or *shale* where thinly bedded. Those composed principally of sand-size grains are called *sandstone*, and those containing abundant pebbles are referred to as *conglomerate*. These terms do not imply any conditions regarding color or mineral composition of the rocks, for types of source materials are different from place to place. Thus shale

may be light-colored or white where composed of pure clay, dark gray where it contains carbonaceous material (charcoal-like plant debris), or brown where a little iron oxide is present. Ordinarily the coarse sand and pebble-size fragments in these rocks are somewhat rounded from being rolled along stream beds. If these larger fragments are angular, indicating very rapid or unusual conditions of deposition, special names are applied to the rocks by geologists. Thus sandstone with angular grains is called *graywacke* or *arkose*, where the rocks are dark or light gray, respectively. Coarse-grained rocks equivalent to conglomerate, but with the large fragments being angular rather than rounded, are called *breccia*. These types, particularly graywacke, are abundant in California.

In addition to detrital material carried mechanically by water, wind, glaciers, and landslides, large amounts of the soluble constituents of rocks are also carried by being dissolved in water. Although mountain streams may appear to be very pure to the taste, they always carry significant amounts of chemical material in solution, as can be determined by chemical analysis. This, combined with evaporation of the water, is how interior basin lakes, such as Great Salt Lake and the Salton Sea, become so salty. Under favorable conditions, some or all of this dissolved material is precipitated by evaporation of lakes, or of bays that become isolated from the sea, to form deposits of great commercial value. Such deposits, known collectively as *evaporites*, include extensive layers of various salts, particularly *rock salt* and *gypsum*.

Precipitation of material dissolved in the waters of lakes and seas is also accomplished in a more complex manner by living organisms. Marine animals such as corals and shellfish extract calcium carbonate from the water in order to construct their shells of calcite; then when the animals die their shells accumulate on the ocean bottom. Where conditions are favorable, accumulations of such shell material are sufficiently large to form extensive thick beds that become *limestone* when cemented together. In a like manner, the microscopic aquatic plants called diatoms extract silica (silicon dioxide) from water to make their decorative siliceous shells. Where silica is abundantly dissolved in water, diatoms reproduce so rapidly that pure white deposits of these tiny shells accumulate to form *diatomite*, a rock of commercial value.

The study of sedimentary rocks is very important to our interpretation of geologic history. These are the rocks in which fossils are found, from which the life history of the earth is studied. In addition, the nature of sediments often yields much information regarding climate and surface relief during the time of deposition; and folding and faulting of originally flat strata testify to periods of mountain building (orogeny). And, of course, these rocks tell us of the former distribution of seas so that we can reconstruct the history of geographic changes of the earth's surface.

3. **Metamorphic rocks** are those that have formed by recrystallization of igneous or sedimentary rocks under the influence of heat, pressure, and chemically active fluids deep within the crust of the earth. Such changes have taken place below the melting temperatures of the rocks, otherwise the resulting rocks would be igneous.

Perhaps metamorphism and the metamorphic rocks can be most easily understood if one remembers that chemical compounds (including minerals) are stable only within limited chemical and physical environments. For example, we know that at high temperatures and in the presence of oxygen, common organic compounds like wood and coal combine with oxygen to burn and produce new compounds, principally carbon dioxide and water. In other words, wood and coal are not stable at high temperatures in the presence of oxygen.

In a similar way, many of the minerals found at or near the surface of the earth are not stable under the high pressures and temperatures that exist at depths of several miles. When buried to such depths, these minerals react with each other, and with fluids present in the rocks, to form new minerals. Geologists call this process metamorphism. (Conversely, when these minerals formed at high temperatures and pressures become exposed at the surface by mountain building and erosion, they are relatively unstable and gradually react with water and the atmosphere to form new minerals that are stable under surface conditions. The latter process is called weathering.)

As an example of the metamorphism of a sedimentary rock, we might trace the transformation of mudstone, a sedimentary rock, to slate and schist, two types of metamorphic rock. When deposited on the ocean floor *mudstone* is composed predominantly of very fine-grained clay and quartz. As a thick sequence of sediments is deposited on our mudstone, it is gradually buried to a depth of many thousands of feet, that is, to an environment of higher temperatures and much higher pressures than exist at the surface. Even here, under a static load, the minerals may resist recrystallization and the rock remain a mudstone. But chemical reaction and recrystallization within such a rock in this environment will be triggered by the introduction of shearing stresses that accompany mountain building within the earth's crust. Abundant fine-grained mica, a flaky mineral, forms at the expense of the clay, with the tiny new flakes all oriented in one plane parallel to the shearing forces. The resulting rock is *slate*, a hard, fine-grained rock with remarkably uniform platy cleavage. Quartz is stable under these conditions, so remains as tiny grains, but both it and the mica are too fine-grained to be identified without a microscope.

If the shearing stresses increase and the temperature rises a little, bunches of the tiny mica flakes in the slate recrystallize to form larger mica flakes that are also roughly parallel to each other, while the tiny quartz grains recrystallize to form larger quartz grains. The resulting rock is a *schist*, a flaky, shiny rock with mineral grains sufficiently large to be seen with the unaided eye, and entirely different in appearance from the original mudstone.

Other types of metamorphic rocks are the result of recrystallization of rocks under the influence of moderate heat and low or high confining pressures, without shearing stresses playing an important role. Under such conditions there is no preferred direction of crystal growth, and the new rocks will be massive, without foliation or cleavage. The *greenstone* specimen in the set is an example of this type of metamorphic rock, derived from *basalt.*

Because we are able to reproduce many of these reactions in the laboratory, both the minerals and textures of the various metamorphic rocks reveal much information to the geologist regarding the conditions under which they were formed. In addition, the exposure of metamorphic rocks at the surface in any area indicates uplift or mountain building there at some time in the past, and removal by erosion of a considerable thickness of overlying rocks.

Descriptions of Specimens in the Set

Characteristic outcrop of thin-bedded chert. In many places the chert beds are highly contorted. *Photo by Mary R. Hill.*

1. BARITE

Composition—barium sulfate ($BaSO_4$)
Color—white, but with impurities inclining to yellowish, gray, or brown
Luster—vitreous
Hardness—2.5 to 3.5
Streak—white
Cleavage—three perfect cleavages
Specific gravity—4.5
Crystal system—orthorhombic

Barite is a heavy white or light-colored mineral composed of barium, sulfur, and oxygen. It is a relatively soft mineral, so that it can be scratched with a copper penny, but not with the fingernail. The crystals are tabular and have three perfect cleavage directions that yield tablet-shaped fragments when crushed. However, most barite is too fine-grained for crystals or cleavage to be observed without the aid of a microscope.

Fine-grained aggregates of barite may appear similar to limestone or quartz, but the high specific gravity readily distinguishes it from these and other similar-appearing rocks and minerals. This quality can easily be detected by hefting the specimen and comparing its apparent weight with that of a specimen of limestone, calcite, or quartz of similar size.

Barite is commonly found in veins containing metallic minerals, such as ores of silver, lead, and copper. It also occurs as veins and masses of pure barite, especially associated with limestone.

The principal commercial use of barite employs its high specific gravity. The mineral is finely ground and added to oil well drilling mud to increase the weight of the mud in order to confine gas pressures encountered in drilling. It is also used in the paint industry and in several other industrial applications.

Barite has been mined at a number of widely distributed localities in California.

2. CALCITE

Composition—calcium carbonate ($CaCO_3$)
Color—Most commonly white, gray, or clear, rarely bluish. With impurities may be variously tinted red, green, yellow, brown, or black
Luster—vitreous or earthy
Hardness—3
Streak—white
Cleavage—three highly perfect cleavages at oblique angles (rhombohedral)
Specific gravity—2.7
Crystal system—hexagonal

Calcite is a relatively soft mineral, and can be scratched by a copper penny. Its three perfect cleavages yield characteristics rhomb-shaped fragments bounded by flat, shiny surfaces. The mineral is easily soluble in acids, with liberation of carbon dioxide (CO_2) making the reaction effervescent. Since this reaction can be observed even when weak acids like vinegar (acetic acid) are put on calcite powder, it is a good test for the mineral. Calcite is often confused with quartz, but can easily be scratched with a knife whereas quartz cannot.

Calcite is one of the most common minerals of the earth's crust. It is the predominant mineral comprizing such abundant rocks as limestone and marble, and also occurs as a subordinate constituent in many other rocks. White veins of pure calcite can be found penetrating various rocks in many areas of California.

Calcite has numerous uses as the predominant constituent of limestone, so these are mentioned under the description of that rock. Large water-clear crystals or cleavage rhombs of calcite are called *Iceland spar*. Such crystals give a double image of things viewed through them, and are of value for the manufacture of various optical instruments, particularly in the production of Nicol prisms to produce polarized light.

3. CHROMITE

Composition—oxide of chromium and iron ($FeCr_2O_4$)
Color—black to dark brownish black
Luster—metallic to submetallic, sometimes pitchy
Hardness—5
Streak—brown
Cleavage—none
Specific gravity—4.6
Crystal system—isometric

Chromite is a heavy, black mineral that has about the same specific gravity as barite. Its hardness is close to that of steel, but it can usually be scratched with a knife blade. The brown streak (powder of the mineral) ordinarily distinguishes chromite from other similar-appearing heavy black minerals, for most of these have black streaks.

Chromite occurs only in peridotite and serpentine, two closely related rock types, or in sand and gravel derived from these rocks. In its host rocks it is normally present as tiny disseminated grains, but in places is concentrated in masses sufficiently large to be mined.

Chromite is the only ore mineral of chromium, an important metal that strongly resists corrosion. This metal is an important constituent of stainless steel, and is also used as thin plating to protect the surfaces of other metals that corrode more easily. Chromite is also used in the manufacture of chromium chemicals, that find wide application in leather tanning, pigments, and other industrial uses. In addition, chromite has such a high melting point that it is made into bricks for lining steel-making furnaces.

Chromite is a relatively common ore mineral in the Coast Ranges, Sierra Nevada, and Klamath Mountains, and California is the leading producer of the mineral in the United States.

4. CHRYSOTILE

Composition—hydrous magnesium silicate ($H_4Mg_3Si_2O_9$)
Color—pale green to white
Luster—silky
Hardness—about 3
Streak—white
Cleavage—perfect, fibrous
Specific gravity—2.2
Crystal system—monoclinic

Chrysotile is a mineral that separates into strong, flexible fibers. It is found as veins in serpentine rock, normally with the fibers oriented nearly perpendicular to the direction of the vein. These veins range in thickness from that of a pencil line to more than an inch, but most chrysotile veins are less than ⅛ inch thick. The color of chrysotile in the vein is green to greenish white, rarely golden, but when separated into a fluffy mass the fibers are white. Individual fibers are somewhat stronger than silk, and a bundle of fibers the diameter of a pencil lead cannot be broken by pulling between the fingers.

Chrysotile is the principal asbestos mineral of industry. The term "asbestos" is a commercial one, applied to half a dozen fibrous minerals that are used primarily because of their fibrous characteristics. Of these, chrysotile is one of the strongest, and is also the most abundant; so it accounts for about 95 percent of the asbestos produced in the world.

Serpentine containing chrysotile veins is mined at several localities in California for production of asbestos. The rock is crushed and passed over tilted shaking screens, allowing the small serpentine fragments and dust to fall through the screens and the fluffy fibers to be lifted from the end of the screens by air suction.

Close-up of ½-inch chrysotile veins in serpentine.

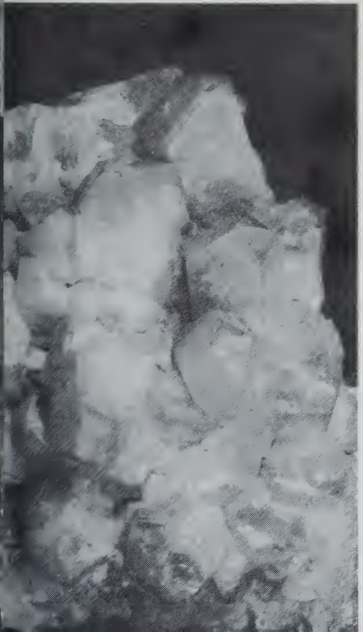
5. COLEMANITE

Composition—hydrous calcium borate ($Ca_2B_6O_{11}.5H_2O$)
Color—colorless to white
Luster—vitreous
Hardness—4
Streak—white
Cleavage—one perfect cleavage
Specific gravity—2.4
Crystal system—monoclinic

Colemanite is similar in appearance to calcite, but the two can be differentiated by some simple tests. When a small fragment of colemanite is held with tweezers in a gas flame, the fragment decrepitates (tiny fragments are thrown off violently, with a crackling sound), and the flame is colored green. Also, colemanite does not effervesce in acids, as does calcite.

Most of the colemanite specimen material for these sets is composed of aggregates of small crystals, and the flat, shiny surfaces are crystal faces rather than cleavage surfaces.

Colemanite deposits originated by evaporation of boron-rich water in desert basins. Once crystallized, however, colemanite is not easily dissolved in water, so it is abundant in some of the very old dry-lake sediments of the Mojave Desert region. Before the discovery of borax deposits in California, colemanite was mined and converted into borax (sodium borate) by chemical processes. Now it is mined largely for use in ceramic glazes.



Cluster of large colemanite crystals, the largest about 2 inches across.

6. EPIDOTE

Composition—silicate of calcite, aluminum, and iron ($HCa_2(Al,Fe)_3Si_3O_{13}$)
Color—pistachio green or yellowish green to dark green
Luster—vitreous
Hardness—6 to 7
Streak—white
Cleavage—one perfect cleavage
Specific gravity—3.4
Crystal system—monoclinic

Epidote is a colorful mineral of metamorphic origin that is relatively common in some parts of California. Its characteristic pistachio green color, hardness (harder than a knife blade), and relatively high specific gravity are usually sufficient for identification of this mineral. Most commonly it is found in compact masses of tiny grains, the latter too small to be individually distinguished without the aid of a hand lens or microscope. But in places it is found in coarsely crystalline aggregates so that the elongate, vitreous crystals can be easily distinguished. It is most commonly associated with white quartz and calcite and reddish-brown garnet.

Epidote is one of the characteristic minerals formed when limestone is metamorphosed by high temperatures and fluids emanating from granitic magma. Thus it is most abundant in areas where granitic rocks are exposed. It is also a constituent of some schist, but is not particularly apparent in these rocks.

Epidote has no commercial value, but is significant to the geologist in that its presence near granite commonly indicates metamorphic zones in which tungsten and molybdenum ores may be found.

7. FELDSPAR

Composition—a group of minerals, alumino silicates of potassium, sodium, and calcium
Color—white, pinkish, gray, clear; rarely pale yellow or green
Luster—vitreous
Hardness—6 to 6.5
Streak—white
Cleavage—perfect in two directions
Specific gravity—2.5 to 2.9
Crystal systems—monoclinic and triclinic

Feldspar is not a single mineral, but is the name applied to a group of closely related and similar-appearing minerals that have almost identical lattice structures. Collectively, they are the most abundant rock-forming minerals in the crust of the earth. Geologists apply separate names to individual minerals in the feldspar group, but they are so similar in physical properties that they are very difficult to distinguish by simple tests. The most abundant feldspar minerals are microcline and orthoclase (both of which have the chemical formula $KAlSi_3O_8$), albite ($NaAlSi_3O_8$), and anorthite ($CaAl_2Si_2O_8$). The specimen is orthoclase.

Characteristics that help to distinguish feldspar from other similar-appearing minerals are its hardness, cleavage, and the nature of its occurrence. None of the minerals of the feldspar group can be scratched by a knife blade, but they can be scratched with a steel file. They have two prominent cleavage directions at, or very nearly at, right angles to each other.

As to the nature of occurrence of feldspar minerals, they comprise the bulk of the light-colored minerals in igneous rocks. They are especially distinguishable in such rocks as white or light-colored crystals that are lath shaped or rectangular in outline. Grains of quartz, the other principal light-colored mineral in igneous rocks, tend to have irregular outlines and do not exhibit flat cleavage faces.

Feldspar is also an important constituent of many sedimentary and metamorphic rocks. Generally it is considerably more difficult to identify feldspar in these rocks than in igneous rocks because of the lack of the distinctive rectangular outline.

The feldspar minerals are commercially important, being used in large quantities in the manufacture of ceramic glazes and glass. In addition, the alteration of feldspar by weathering is the principal source of clay, an extremely important constituent in most soils.

8. LIMONITE

Composition—hydrous iron oxide (Fe_2O_3 with H_2O)
Color—various shades of brown, ochre yellow, rarely black, and in places with an iridescent coating
Luster—dull and earthly, but submetallic in places
Hardness—soft to moderately hard
Streak—yellowish-brown
Cleavage—none
Specific gravity—about 3½ to 4
Crystal system—none (not a crystalline substance)

Limonite is not a mineral in the technical sense, for it is a mixture of molecules of iron oxide and water in various proportions, without a fixed arrangement of the constituent atoms (such natural materials are commonly called "mineraloids"). However, it is a widespread material at and near the surface of the earth, and is one of the principal inorganic "coloring agents" of our landscapes, lending yellowish, brown, and reddish-brown colors to the surface rocks and soils.

Limonite is a product of weathering (oxidation) of minerals that contain iron. Typically it is disseminated in most soils, giving them brown or buff colors, and is present as thin coatings along fractures in the rock below the soil. Traces of such brown limonite coatings can be observed on some of the rock specimens in the set, masking the true color of the rock where it is present.

The limonite specimen comes from the weathered surface of a massive pyrite ore body in Shasta County, and may have a honeycomb structure.

Although common and widely distributed, limonite does not occur in masses of high purity that are sufficiently large to be mined as iron ore. Its principal use is as a pigment in paints.

9. MAGNESITE

Composition—magnesium carbonate ($MgCO_3$)
Color—white or gray; yellow or brown with impurities
Luster—vitreous
Hardness—3½ to 5
Streak—white
Cleavage—three perfect cleavage directions, similar to calcite, but not visible on the specimen
Specific gravity—3.0 to 3.2
Crystal system—hexagonal

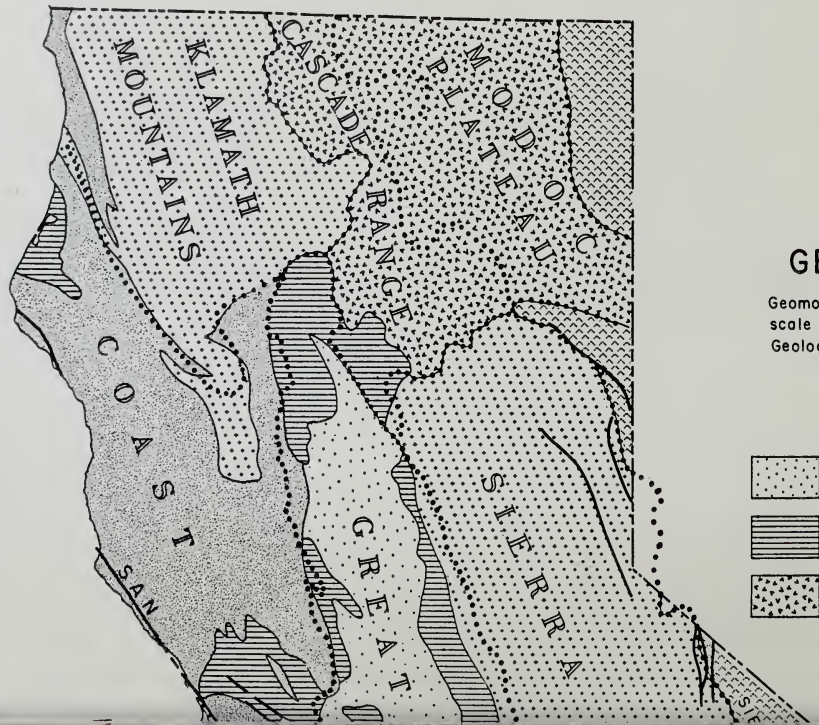
Magnesite is closely related to calcite, and the two minerals are similar in most physical properties. However, magnesite is slightly heavier and harder than calcite, is less readily soluble in acids, and is not nearly as abundant. Magnesite cannot be scratched with a copper penny but it can be scratched with a knife blade, and it will effervesce only in strong hot acids.

Crystals of magnesite have perfect cleavage, but the specimen is made up of an aggregate of very tiny magnesite grains so this cleavage is not visible. Large crystals of this mineral are rare.

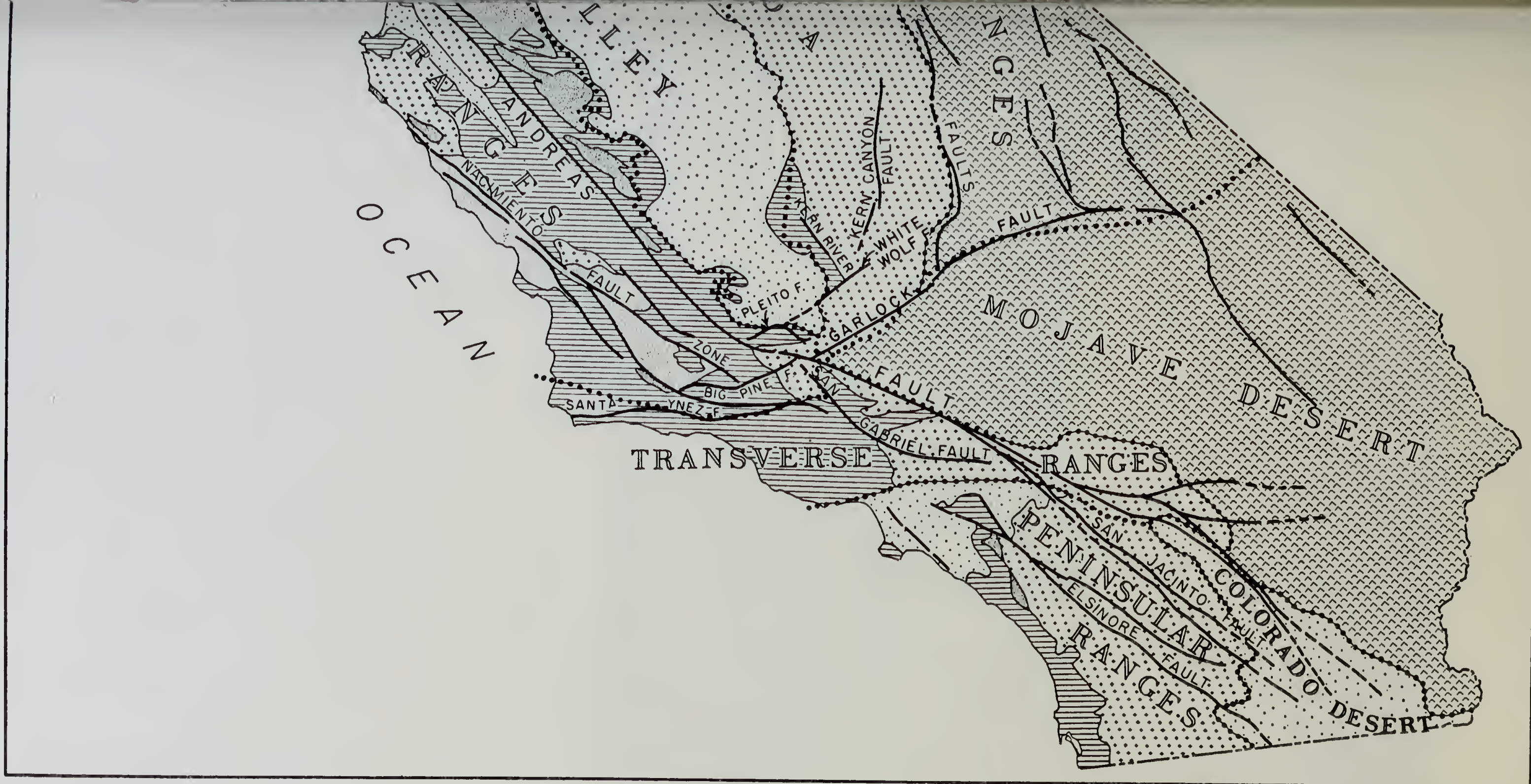
In California, magnesite occurs principally as white veins in serpentine, a dark green rock. Such veins are characteristically an inch or so thick, but in places they are several feet thick. Magnesite has been mined from many of the larger veins, and used in the manufacture of a special type of cement (called magnesium oxychloride cement, or simply "magnesite"). The mineral also is mined for production of magnesium chemicals and magnesium metal.

MAP OF CALIFORNIA SHOWING GEOMORPHIC PROVINCES AND GENERALIZED GEOLOGIC UNITS

Geomorphic provinces from Jenkins, Olaf P., 1938, Geomorphic map of California, scale 1:2,000,000. Geologic units generalized from Jenkins, Olaf P., 1938, Geologic map of California, scale 1:500,000



- Quaternory sedimentary rocks
- Tertiary sedimentory rocks
- Quaternary and Tertiary volcanic rocks of CASCADE RANGE and MODOC PLATEAU
- Mesozoic sedimentary rocks
- Mesozoic – Paleozoic metamorphic and granitic rocks.
- Pre-Cambrian to Recent rock complex of the BASIN-RANGE and MOJAVE DESERT
- Geomorphic province boundary



MOJAVE DESERT
COLORADO DESERT
PENINSULAR RANGES
SAN JACINTO FAULT
ELSINORE FAULT
TRANSVERSE RANGES
SAN ANDREAS FAULT ZONE
GARLOCK FAULT
WHITE WOLF F.
KERN CANYON FAULT
KERN RIVER
FAULTS
NGES
PLEITO F.
BIG PINE F.
SANTA YNEZ F.
SAN GABRIEL FAULT
NACIMIENTO FAULT
LLEY
RANGES
OCEAN

10. MAGNETITE

Composition—iron oxide (Fe_3O_4)
Color—black
Luster—metallic
Hardness—6
Streak—black
Cleavage—none
Specific gravity—5.2
Crystal system—isometric

Magnetite is a heavy black mineral that is easily identified because it is strongly attracted by a magnet. A few other minerals are weakly attracted by magnets, but they either do not look like magnetite or their streaks are not black. Magnetite from some localities acts as a natural magnet (that is, will attract iron filings), and is called lodestone.

Magnetite is a relatively abundant mineral, for it is a minor constituent of many different types of rocks. Where it is sparsely disseminated as large grains in some rocks, the characteristic octahedral crystal form of magnetite is often identifiable. However, the grains are most commonly irregular in shape.

Being an oxide, magnetite is highly resistant to alteration by weathering, so grains of it tend to accumulate in sands. As a result, the easiest way to find magnetite is to thrust a magnet into the sand of almost any stream or beach.

Magnetite is a very important mineral to our industrial economy, for it is one of the principal ore minerals of iron.

11. MANGANESE OXIDES

Composition—largely manganese oxide (several different minerals)
Color—black, rarely brownish black
Luster—metallic to dull
Hardness—1 to 6
Streak—dark brown to black
Cleavage—none
Specific gravity—4 to 5

Manganese combines with oxygen in a variety of different proportions and different lattice arrangements to yield a variety of minerals. These are typically fine grained, and difficult to tell apart. They vary widely in hardness, from soft, soot-like material to hard metallic-looking masses. Manganese oxide is most apparent as thin black crusts or stains on natural fracture surfaces of many different rock types, particularly near the surface where the rocks are weathered. The most striking of these crusts show branching dendritic patterns, commonly appearing as if moss had been pressed into the rock.

Where manganese oxide occurs in relatively pure masses it is mined as manganese ore, another very important raw material in our economy. Manganese metal extracted from this ore is alloyed with iron to make steel. Manganese oxide is used in the manufacture of various chemicals, to decolorize glass, and in flashlight batteries.

Manganese oxide has been mined at numerous localities in California. In the Coast Ranges, Sierra Nevada, and Klamath Mountains these deposits are typically found in chert. In the Mojave Desert region they are associated with volcanic rocks.

12. MICA (Muscovite)

Composition—silicate of potassium and aluminum ($H_2KAl_3Si_3O_{12}$)
Color—clear, white, gray, or greenish
Luster—vitreous to pearly
Hardness—2
Streak—white
Cleavage—very perfect in one direction
Specific gravity—2.7 to 3.1
Crystal system—monoclinic

Mica is the family name of a group of closely related minerals that have very perfect cleavage in one direction only, and can be split into exceedingly thin sheets or flakes. The most abundant minerals in this group are muscovite (represented by the specimen) and biotite, a black or dark-brown mica. The color difference is caused by the presence of iron and magnesium in biotite. These minerals are important constituents of many types of igneous and metamorphic rocks.

Mica is usually easy to identify because of its perfect cleavage, and the fact that thin cleavage plates or flakes are very flexible and elastic. It is sufficiently soft to be scratched with the fingernail, a property that helps to differentiate it from other minerals with which it is commonly associated.

Various of the mica minerals are of considerable commercial value. Large cleavage plates of muscovite are used as insulation in the manufacture of electrical apparatus. A variety of biotite, called vermiculite, swells when heated, and is extensively used in heat and sound insulating. A pink, lithium-bearing member of the mica family, called lepidolite, is used as a source of lithium and in the manufacture of glass.

13. PYRITE

Composition—iron sulfide (FeS_2)
Color—pale brassy yellow
Luster—metallic
Hardness—6
Streak—greenish black
Cleavage—none
Specific gravity—5
Crystal system—isometric

Pyrite is a heavy, metallic-appearing mineral that is often mistaken for gold because of its color. However, it is not really metallic, but brittle, and has a greenish-black streak (gold is malleable, and has a gold-colored streak). Where it is disseminated in rocks, pyrite commonly exhibits its most frequent crystal form, the cube. These cubic crystals are so diagnostic of pyrite that when they are present, the mineral can be recognized even though the crystal surfaces are altered to brown limonite, which is often the case. But much pyrite is fine-grained or massive, and does not have crystal faces. The fact that pyrite cannot be scratched with a knife blade is usually sufficient to distinguish it from other similar-colored sulfide minerals, for with one exception they are all softer than steel. The only other sulfide mineral equally hard is a relatively rare one, marcasite, that has the same chemical formula as pyrite, but a different lattice structure.

Pyrite is a relatively abundant and widespread mineral, occurring in places in all types of rocks. It is perhaps best known for its occurrences in quartz veins, where it is commonly associated with gold and other metallic ore minerals. Thus, when pyrite is found in a quartz vein, it is an indication to the geologist and prospector that valuable metals *may* be present in the vein. Pyrite itself is of value as an ore of sulfur, and a large deposit of it in Shasta County is mined for this purpose.

14. QUARTZ

Composition—silicon dioxide (SiO_2)
Color—clear, white, or gray, rarely purple or yellow
Luster—vitreous
Hardness—7
Streak—white
Cleavage—very poor (conchoidal fracture much more conspicuous)
Specific gravity—2.65
Crystal system—hexagonal

Quartz is one of the most abundant minerals of the earth's crust, being an important constituent of many types of rocks and the major constituent in most sand. It is a hard, brittle mineral that has no apparent cleavage. Like glass, it breaks with a characteristic conchoidal fracture. It cannot be scratched with a knife, as can many of the minerals with which it might be confused, and it will easily scratch glass.

Most people have picked up or seen quartz crystals, which are characteristic six-sided prisms terminated by six-sided pyramids. Such crystals usually are clear and colorless, although some are gray (smoky quartz) or violet (amethyst). But crystal faces develop only in special environments, such as open fissures or cavities in rock, and most quartz occurs as disseminated irregular grains in many different types of rocks. It also occurs as massive white aggregates of irregular grains, such as milky vein quartz. Quartz is much more resistant to alteration by weathering than are most other minerals, so it is a prominent constituent of beach and stream gravels, and smaller grains accumulate as sand.

Quartz is mined for a wide variety of industrial uses. Large quantities are processed in the manufacture of glass and ceramic materials, and are used in the manufacture of cement and as a metallurgical flux. Carefully cut sections of clear quartz crystals are used as crystal oscillators to control the frequency of radio transmitters, and clear or attractively colored crystals are cut for gem stones.

In many places veins of milky quartz contain disseminated gold or minerals of other valuable metals. Where the content of one or more valuable metals is sufficiently high, such veins are mined.

15. QUARTZ, variety chalcedony

Composition—silicon dioxide (SiO_2)
Color—translucent white or gray; but with impurities may be almost any color, or opaque; commonly banded in white, gray, and other colors
Luster—waxy
Hardness—7
Streak—white
Cleavage—none (fracture conchoidal)
Specific gravity—2.6
Crystal system—hexagonal, but always so fine-grained that individual crystals cannot be observed except by very great magnification

Chalcedony is the name applied to microfibrous masses of quartz that have a waxy luster. The individual quartz fibers are so small that they can be seen only with special apparatus and a high-power microscope. Minute water-filled pores between the tiny fibers result in masses of chalcedony having lower specific gravities than quartz, and also are probably the cause of chacedony having a waxy luster instead of being vitreous like typical quartz. However, the hardness is 7, as is that of coarsely-crystalline quartz.

Pure chalcedony is colorless, white, or grayish, and is translucent or transparent. However, it is commonly brown, red, yellow, green, bluish, or dark gray because of small amounts of finely divided colored minerals disseminated among the quartz fibers.

Chalcedony is relatively abundant in California. It is the predominant constituent of chert, a common rock in the state, and occurs lining or filling fissures and other cavities in various rocks, particularly volcanic rocks. When deposited in wide fissures, masses of chalcedony often assume globular or stalactitic forms. Chalcedony is also found in many places where it has replaced other materials, commonly retaining the form and texture of objects replaced. An example of the latter is petrified wood.

The principal use of chalcedony is as gem material, and many gem names are applied to variously colored or patterned chalcedony. When banded, it is called *agate*, when red or yellow and opaque it is called *jasper*, when translucent green it is *chrysoprase*, and when translucent orange it is *carnelian*. *Flint* is dark gray or brown chalcedony.

Left. Cluster of colorless quartz crystals, illustrating characteristic prismatic form terminated by 6-sided pyramid.

16. SULFUR

Composition—sulfur (S)
Color—sulfur yellow, grayish
Luster—resinous
Hardness—1.5 to 2.5
Streak—white
Cleavage—poor
Specific gravity—2
Crystal system—orthorhombic

Sulfur is a soft, yellow mineral that easily burns with a bluish flame, giving off the pungent odor of sulfur dioxide. These characteristics, in addition to its resinous luster, allow it to be easily distinguished from other minerals.

Sulfur is a relatively common mineral in active or recently active volcanic areas, where it typically forms incrustations in fissures and on rocks at the surface. In places it occurs in large, relatively pure deposits that can be mined. Notable deposits of sulfur in California are found in Alpine County and in the Last Chance Range, Inyo County.

It is principally used to manufacture sulfuric acid, which is very important to industry. Sulfur is also used in fertilizers, insecticides, explosives, rubber, and paper.

17. TALC

Composition—magnesium silicate ($H_2Mg_3Si_4O_{12}$)
Color—white, gray, light to dark green
Luster—pearly or greasy
Hardness—1
Streak—white
Cleavage—perfect in one direction
Specific gravity—2.7
Crystal system—monoclinic

Among the most distinguishing features of talc are its softness and greasy feel. It is easily scratched with the fingernail, and will even make a mark on cloth. None of the common minerals with which it might be confused are this soft.

Most talc occurs in fine-grained, impure masses called talc schist when foliated, or soapstone if they are massive and compact. In many places, though, coarse flaky talc is found that is pale green or white, and may resemble muscovite. Aside from the recognizable difference in the hardness of these two minerals, cleavage flakes of talc are not elastic (that is, they will stay bent when flexed), in contrast to mica flakes that are elastic, which do not stay bent.

Talc is found only in metamorphic rocks, ordinarily formed from dark minerals rich in magnesium and iron. In fact, one of the commonest occurrences of the mineral in California is in talc schist derived by metamorphism of serpentine, itself a metamorphic rock.

Talc is a valuable industrial mineral. It is finely ground for use in the manufacture of ceramics, paint, and rubber, and in the preparation of special lubricants, talcum powder, and insecticides. Slabs of soapstone are used for electrical switchboards and laboratory table tops.

The southern Death Valley region of California is one of the principal sources in the world for talc of high purity that is needed by manufacturing industries.

Left. Cluster of sulfur crystals, the largest here about an inch long.

Characteristic outcrop appearance of granite in the mountains of California. *Photo by C. W. Chesterman.*

18. GRANITE

Type of rock: igneous, coarse grained
Mineral content: feldspar, quartz, biotite, hornblende

Granite is a coarse-grained igneous rock, the mineral grains being easily seen with the unaided eye and being largely uniform in size. This rock is composed predominantly of feldspar and quartz, both white or light-colored minerals, so that large masses of granite typically appear white or light gray from a distance. Minor amounts of biotite (black mica) or hornblende (also black), or both of these, are present in granite and give the rock a speckled appearance at close range.

The terms "granite" and "granitic rocks" are commonly used to designate a number of similar-appearing plutonic igneous rocks that are slightly different in their chemical composition. Such differences are significant to the geologist, so for detailed study he applies different names to these rocks according to the relative amount of quartz they contain, and the types and relative abundances of the feldspars and dark minerals present. Included among the granitic rocks are granite, granodiorite, diorite, monzonite, and syenite, all generally similar in appearance to the untrained eye, but distinguishable on the basis of detailed mineral analyses of the rocks.

Granite is formed at considerable depth by very slow cooling and crystallization of magma. Yet it is one of the most abundant rock types exposed at the surface in California, testifying to the great extent of uplift and erosion in the mountainous areas where it is found in the state.

Recently the amount of decay of certain radioactive elements present in granite specimens collected at various localities in California has been studied. This work indicates that most of the granite in the state crystallized 75,000,000 to 100,000,000 years ago. Some masses, however, are much older.

Granite is of commercial value as building stone. It is also of considerable indirect economic significance, for the formation of many ore deposits, especially those of gold, copper, and tungsten, are related to the igneous phenomena associated with the formation of granitic rocks.

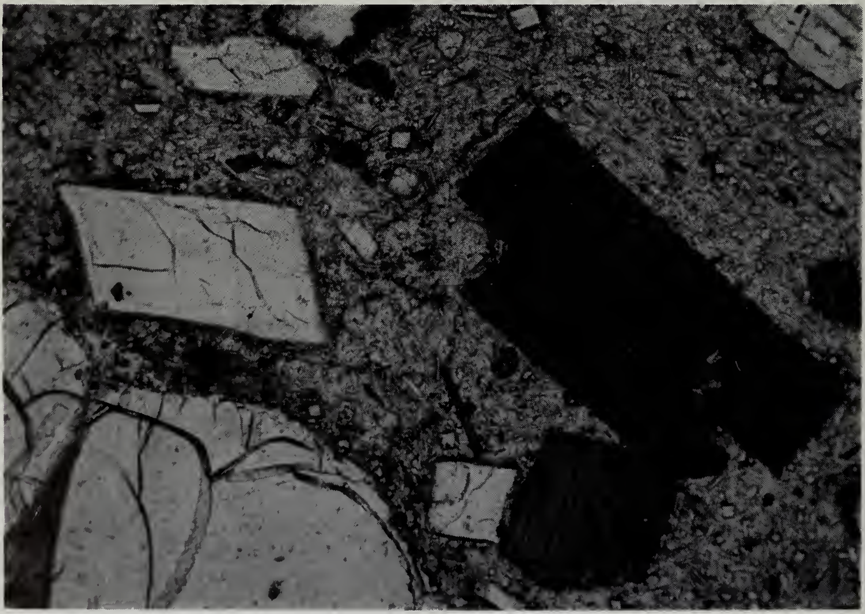
19. GABBRO

Type of rock: igneous, coarse grained
Mineral content: feldspar, hornblende

Gabbro is a coarse-grained igneous rock composed essentially of white feldspar and one or both of the similar-appearing black minerals, hornblende and augite. Much of the gabbro in California is similar to the specimen in the collection, containing only hornblende as the black mineral.

Gabbro is a plutonic igneous rock, like granite, but the two are significantly different in chemical composition. Containing substantially less silicon and more iron and magnesium than granite, gabbro has no quartz and is rich in dark minerals. Thus the rock has an over-all dark color, and typically appears coarsely mottled at close range.

Gabbro is found at numerous widely distributed localities in California, but individual outcrop areas are normally smaller than those of granite.



20. RHYOLITE

Type of rock: igneous, fine-grained
Mineral content: feldspar, quartz, hornblende, biotite, volcanic glass

Rhyolite is a light-colored volcanic rock wherein most or all of the individual mineral grains are too small to be identified without the aid of a microscope. It originates when magma of granitic composition is erupted at the surface as a lava flow, so it has a mineral content similar to that of granite. Most rhyolite has a light gray, pinkish, or pale purplish color. In places it exhibits prominent flow banding caused by alignment of gas bubbles.

Microscopic examination of rhyolite specimens reveals that they consist predominantly of very tiny crystals of feldspar and quartz, with some interstitial volcanic glass between the crystals. Scattered large crystals of one or more of the minerals feldspar, quartz, hornblende, or biotite are commonly present and visible with the unaided eye, having started crystallizing from the magma long before eruption, but these normally constitute only a small percentage of the rock.

Rhyolite is one of the characteristic volcanic rocks of continental areas, and is found at numerous localities in California.

Left. **Photomicrograph of rhyolite, magnified about 75 diameters. The large white grain at lower left is quartz, the white tabular crystals are feldspar, and the large dark-colored crystals are biotite (mica). The groundmass is tiny laths of feldspar in a glassy matrix.**

21. BASALT

Type of rock: igneous, fine-grained
Mineral content: feldspar, augite, olivine, magnetite, volcanic glass

Basalt is a dense, fine-grained volcanic rock that is typically black or dark gray. It may contain scattered visible crystals of minerals that formed prior to eruption. It originates by volcanic eruption of the same type of magma that yields gabbro when cooled at great depth.

When examined under the microscope, basalt is seen to consist of a multitude of tiny lath-shaped feldspar crystals and stubby augite crystals, commonly with interstitial volcanic glass. Fine-divided grains of magnetite (visible only with the microscope) are peppered throughout the rock; although they only constitute a small percentage of the rock, they are partly responsible for the black color of basalt. Small grains of olivine, a green, magnesium-rich mineral, are visible in some basalt.

Spherical or ellipsoidal cavities are present in most basalt, and tend to be particularly abundant in specimens taken from the tops of lava flows. These represent bubbles of gas trapped in the rock when the magma solidified. In many places such cavities are coated with tiny crystals of light-colored minerals deposited from the gasses, and may even be filled with these minerals.

Basalt is particularly characteristic of the oceanic basins; for example, the Hawaiian Islands are basalt volcanoes that rise from the deep ocean floor. However, large quantities also have been erupted in certain continental areas, and basalt is found in many parts of California.

22. OBSIDIAN

Type of rock: igneous, glassy
Mineral content: none, composed of volcanic glass

Obsidian is a glassy volcanic rock. It originates when relatively pure granitic magma (essentially free of mineral crystals) flows from fissures at the surface and solidifies so rapidly that crystallization of minerals cannot take place.

Most obsidian is black or gray, but rarely it is reddish brown. It commonly exhibits flow banding in the form of thin layers having slightly different shades of color. Like artificial glass, obsidian is quite brittle and has conchoidal fracture (breaks along characteristic curved, shell-like surfaces). Thin edges of obsidian are translucent.

To primitive man, obsidian was an exceedingly important raw material for the manufacture of tools and weapons. The ease with which fragments could be shaped by flaking, and the exceeding sharpness of flaked edges made obsidian, where available, preferable to flint for these purposes. (Students and teachers should take heed of this fact in handling obsidian specimens, for it is quite easy to obtain a nasty cut if one is careless.)

An interesting modern use of obsidian is in the manufacture of the mirror lenses for reflecting telescopes. In some respects obsidian is superior to the best artificial optical glass for this purpose.

Obsidian is found at a number of localities in California; notably at Glass Mountain, Siskiyou County; Davis Creek, Modoc County; in the Clear Lake area, Lake County; in the vicinity of Mono Lake, Mono County, and at the south end of Salton Sea, Imperial County.

Left. Photomicrograph of basalt, magnified about 75 diameters. The large clear crystal of feldspar and smaller gray grains of augite are embedded in a groundmass of tiny white feldspar crystals, augite crystals, and black magnetite grains.

23. PUMICE

Type of rock: igneous, highly porous
Mineral content: none, composed of volcanic glass

Pumice is volcanic glass "foam" that results from the violent eruption of obsidian magma heavily charged with gas. An explosive eruption, such as commonly precedes obsidian and rhyolite flows, allows the sudden expansion of gas that was dissolved in the magma under high pressures. Blobs of such magma, blown into the air, cool so rapidly that they solidify before these gas bubbles can escape. Thus pumice consists essentially of gas cells separated by thin cell walls of volcanic glass. This rock is exceedingly light-weight because of the multitude of tiny open cells, and is one of the few rock types that will float on water.

Because of the sharp cutting edges of its thin glass cell walls, pumice is used as an abrasive material. Large fragments are sawed to make abrasive blocks, and small fragments are ground for use as the abrasive in metal polishes, rubber erasers, and other products. Pumice fragments are also used an an aggregate to make lightweight concrete.

Pumice is found in many of the areas where obsidian and rhyolite occur. It is mined in Mono and Siskiyou Counties.

24. CONGLOMERATE

Type of rock: sedimentary, very coarse grained
Mineral content: principally quartz, feldspar, and pebbles of various rocks and minerals

Conglomerate is a sedimentary rock consisting of rounded pebbles, cobbles, or boulders in a matrix of sand. In other words, it is the most coarse-grained of the sedimentary rocks formed by normal mechanical transportation of debris by running water. Although conglomerate is not as abundant as sandstone and mudstone, it is normally found interbedded with these rocks in many sedimentary formations.

The pebbles, cobbles, or boulders in conglomerate are of the more resistant rocks and minerals that crop out in the drainage basins from which they were derived. Materials that are easily broken or altered by weathering do not ordinarily survive the rigors of stream transportation to the final site of deposition. Thus tough, compact igneous and metamorphic rocks, as well as quartz and chert, tend to be abundantly represented in the coarse fraction of most conglomerates.

25. SANDSTONE

Type of rock: sedimentary, medium-grained
Mineral content: largely quartz and feldspar

Sandstone is simply what the name implies, sand grains naturally cemented into stone. Although quartz and feldspar are normally the most abundant minerals in this type of rock, grains of numerous other minerals may be present in small percentages, depending on the composition of the rocks through which the streams passed that transported the sand.

After a bed of sand (or other sediments) has been deeply buried by succeeding deposits, the grains normally become cemented together in one of two ways. Compaction alone is sufficient to convert loose sand into rock, particularly if clay is abundant between the grains. More commonly, water circulating through the sand will deposit mineral material that actually cements the grains together. The most common of these cementing minerals are quartz, calcite, and limonite.

Sandstone can be almost any color, depending principally on the color of the cementing mineral, but to a lesser extent on the color of the predominant minerals present. Sand cemented simply by compaction normally yields rocks that are light-to-dark gray. Most sandstones cemented by calcite or quartz are light gray. Where limonite is the cementing material the rock is brown or reddish, and even a trace of limonite gives the rock a buff color.

The sandstone specimens in most of the sets contain fossil shells. According to paleontologists, these are species that lived during the Cretaceous Period, about 75,000,000 years ago. The cementing mineral for these sandstone specimens is calcite.

Sandstone is used primarily as a building stone. However, the greatest commercial value of this rock is an indirect one, for subsurface beds of sandstone are the principal reservoir rocks for our petroleum resources. Under certain specific circumstances, petroleum accumulates in the pore spaces between the sand grains, and can be pumped out from wells penetrating these beds.

Sandstone is very abundant in California, particularly in the areas designated as "Tertiary sedimentary rocks" and "Mesozoic sedimentary rocks" on the map.

26. MUDSTONE (Shale)

Type of rock: sedimentary, very fine-grained
Mineral content: predominantly clay

Mudstone and shale are closely related sedimentary rocks, both being composed of mud that has been cemented or compacted into rock. Where the rock is essentially massive (that is, hand specimens do not exhibit layers), the rock is called mudstone, but if the rock is thinly layered it is called shale. Collectively, these are the most abundant of the sedimentary rocks.

The specimens in this collection are typical mudstone. They are composed of very fine-grained detrital material, principally clay particles, but also contain finely divided fragments of quartz, feldspar, and other minerals. The dark-gray color is caused by the presence of a trace of charcoal-like organic debris. Where this material or other coloring agents are lacking, mudstone and shale are light colored or white. In places, mudstone and shale are colored buff, brown, or reddish brown by small percentages of limonite.

Mudstone and shale are widely used in the manufacture of bricks. Another use, of increasing importance, is in the manufacture of lightweight aggregate for concrete. For this purpose, the rock is crushed and the small fragments heated in a rotary kiln. At a temperature near 2000° F., near the melting point of the rock, the fragments expand like bread dough because of the formation of innumerable tiny gas bubbles. The resulting expanded fragments are strong, and have only about half the weight of an equal volume of standard sand and gravel aggregate.

White mudstones composed essentially of clay, without iron oxides or other coloring constituents, are commercial sources of clay for making pottery and other ceramic products.

27. LIMESTONE

Type of rock: sedimentary, fine-grained
Mineral content: predominantly calcite

Limestone is a sedimentary rock composed predominantly of calcite. Most limestone is light gray (almost white) to dark gray, but in places it is brown or yellowish because of traces of iron oxide. The individual calcite grains in limestone are normally too small to be seen without the aid of a microscope. This characteristic helps to distinguish it from most marble, a coarser-grained rock of similar composition.

Most limestone was formed by cementation of abundant shell debris that accumulated in places on the sea floor. If formed from calcareous ooze (largely shell debris from tiny marine organisms) it is very fine grained. On the other hand, fossiliferous limestone containing shells and shell fragments of larger organisms such as corals, clams, and snails may appear coarse grained, although individual calcite grains cannot be seen with the unaided eye. Some limestone contains no recognizable fossil remains, and probably originated by inorganic precipitation of calcite from water.

Limestone is a relatively soluble rock, for calcite is slowly attacked by slightly acid ground-water and taken into solution. Caves are formed in this manner by ground-water widening cracks in limestone, finally dissolving out large chambers in places. During the last phase of a cave's history, after it has been drained by uplift of the region, the process is reversed and calcite is deposited within the cave by evaporation of slowly dripping water. The resulting dripstone (stalactites, stalagmites, and other depositional features in caves) strikingly illustrates the inorganic deposition of calcite from solution.

Limestone is found in many widely distributed areas of the state, but is not generally abundant except in some of the desert mountain ranges in southeastern California.

Both limestone and marble (metamorphosed limestone) have a wide variety of important uses in our industrial society. Immense quantities of these rocks are quarried and processed each year for manufacture of cement, plaster, and stucco. They also are used in the process of refining sugar, as a flux in steel manufacture, as raw materials in various chemical industries, and for many agricultural purposes. Limestone, or products manufactured from it, are essential to the manufacture of numerous products such as soap, glue, paint, and glass.

28. CHERT

Type of rock: sedimentary, very fine-grained
Mineral content: predominantly chalcedony

Chert is a hard, brittle type of sedimentary rock that is composed predominantly of chalcedony, a very fine-grained variety of quartz. It is white or gray where lacking in impurities, but is commonly brown, reddish brown, or pale to dark green because of iron-rich minerals disseminated in the rock. In California most chert is thin bedded, individual beds being one or two inches thick and separated from each other by paper-thin layers of shale.

In general, this rock has the physical properties of chalcedony. Its hardness (sufficient to easily scratch glass) is a critical characteristic in distinguishing it from other rocks that may have similar appearances.

Most chert was formed by precipitation of silica from sea water in the vicinity of submarine volcanic eruptions. The marine origin is commonly indicated by the presence in the chert of abundant microscopic remains of radiolaria, tiny marine organisms that have ornate skeletons of opal (a non-crystalline form of silicon dioxide).

Thin-bedded chert is relatively common in California, particularly in the Coast Ranges. It is very resistant to alteration and disintegration by weathering processes, so it tends to crop out more prominently than most other rock types, and colorful pebbles of chert accumulate in streams and on beaches.

Chert has no commercial value as an ore, but nicely colored pieces are polished for making jewelry. Of interest to the prospector is the fact that all of the manganese ore deposits of northern California are found enclosed in chert, and the search for such deposits in this region can effectively be limited to examination of chert outcrop areas.

Right. Photomicrograph of diatoms. Average size of the fossils is about 1/500 inch. *Photo courtesy P. W. Leppla.*

29. DIATOMITE

Type of rock: sedimentary, fine-grained
Mineral content: opal

Diatomite is a soft, light-weight sedimentary rock composed predominantly of the siliceous remains of diatoms, microscopic aquatic plants. Diatoms are unusual, tiny, one-cell plants that have ornate cell walls composed of opal (hydrous silicon dioxide); they live both in fresh water and in the seas. Under favorable environmental conditions, particularly where the water becomes locally enriched in dissolved silicon dioxide, diatoms reproduce so rapidly that their remains accumulate to form pure layers many feet thick on the lake or sea bottom. Such deposits seldom become cemented, but are merely compacted by the weight of overlying sediments to yield a friable, porous rock. Diatomite is much lighter than water, so fragments of it will float until they become saturated.

Diatomite is found in several areas in California, being particularly abundant in some of the marine sedimentary rocks of Tertiary age in the southern Coast Ranges and the Transverse Ranges. Deposits that were formed in fresh-water lakes are exposed in the Modoc Plateau region and in the desert basins of eastern California and Nevada.

Diatomite is of commercial value for a variety of industrial purposes, and is mined in California in large quantities. Being very fine-grained and porous, it is used for filtering impurities from petroleum, chemicals, vegetable oils, antibiotics, varnishes, polluted water, and other liquids. It is also used as a mineral filler in numerous manufactured products, such as paper and plastics, to increase bulk and improve such properties as toughness, elasticity, and absorptiveness. Production in California comes largely from quarries in Santa Barbara County.

30. GYPSUM

Type of rock: sedimentary, fine- to coarse-grained
Mineral content: predominantly gypsum

Gypsum is a name applied to a mineral and to a rock composed predominantly of that mineral. The mineral gypsum is a hydrous calcium sulfate ($CaSO_4 \cdot 2H_2O$). It is colorless or white, is so soft that it can be scratched with the fingernail, and has perfect cleavage that yields pearly or shiny flat surfaces. Gypsum is slightly soluble in water, and a significant amount of it is dissolved in the water of the oceans.

Rock gypsum is one of the sedimentary rock types known as evaporites, so called because they were precipitated by evaporation of water rich in dissolved mineral materials. Most large deposits of gypsum are thick beds deposited when bays or arms of the sea become land-locked, and the water evaporated. The gypsum is normally interbedded with limestone and rock salt that were precipitated at different times as the water evaporated. Gypsum deposited in this manner is white, gray, or brown, and finely granular.

In many arid regions gypsum crystals grow in cracks in the rock and in the soil because of evaporation of ground-water rich in dissolved mineral materials. Deposits of gypsum-rich soil formed in this manner are called gypsite, and are quite earthy in appearance.

Extensive beds of rock gypsum are found in several areas of southeastern California, and gypsite is abundant in some arid parts of the state, particularly in the southern Coast Ranges.

Gypsum is a rock of great commercial value, and is quarried at many localities in California. It is from this rock that most plaster is manufactured. Large quantities are also consumed by the cement industry, for gypsum retards the naturally fast setting time of cement, allowing it to be properly mixed and placed before it hardens.

Although it is commonly abundant in poor arid soils, the chemical ingredients of gypsum are lacking in many soils in moist regions. For this reason, gypsum is mined and sold as a "soil conditioner" to improve the agricultural quality of these otherwise-rich soils.

31. SLATE

Type of rock: metamorphic, very fine-grained
Mineral content: mica, quartz

Slate is an exceedingly fine-grained metamorphic rock that can easily be split into thin, flat slabs or sheets. It is composed predominantly of tiny flakes of mica that lie parallel with each other and give the rock its perfect cleavage, but individual mineral grains cannot be seen without the aid of a microscope. Most slate is black, but in places it is dark greenish gray.

Slate is formed by metamorphism of shale or mudstone, and the nature of this transformation is discussed in the introduction on page 15.

In California, slate is found primarily in the Sierra Nevada and the Klamath Mountains. In the past it was extensively quarried in the Sierra Nevada foothills for thin slabs that were trimmed to make slate shingles. In recent years the slate quarried in California has been crushed for the manufacture of roofing granules.

32. MARBLE

Type of rock: metamorphic, medium to coarse grained
Mineral content: predominantly calcite

Unfortunately, a certain amount of confusion enters into the usage of the term "marble". It is most widely known as a commercial name for limestone and other rocks of similar hardness that have been polished for decorative purposes.

To the geologist, marble is metamorphosed limestone, and like limestone it is composed largely or entirely of calcite. In marble, however, individual grains of calcite can be seen with the unaided eye because of recrystallization of the microscopic calcite particles typically present in limestone. Indeed, size of the calcite grains is often the only means of easily differentiating these two rock types.

Most marble is white or gray but in places it is bluish gray, buff, or other shades of color. It commonly appears streaked with parallel or intersecting planes of dark gray impurities. The physical and chemical tests for this rock, as well as for limestone, are the same as those for calcite.

Marble has the same commercial uses as limestone, and is a very important raw material in our industrial economy. It also remains one of the most desirable of the various rock types that are sawed and polished for decorative stone, and marketed collectively as "marble".

33. MICA SCHIST

Type of rock: metamorphic, medium to coarse grained, foliated
Mineral content: mica, quartz, and feldspar

The term schist is used for a variety of medium- to coarse-grained metamorphic rocks that can easily be split along subparallel planes of weakness into thin flaky fragments. The planes of weakness are caused by the presence in the schist of abundant platy or rodlike minerals that are oriented roughly parallel to each other. As with slate, the parallel orientation of these minerals was caused by directional stresses at right angles to them while the rocks were being recrystallized. But the larger grain size in schist does not permit as perfect cleavage as that of slate. In naming these rocks, the word "schist" is preceded by the name of the platy or rodlike mineral that makes it schistose.

Mica schist is composed essentially of mica, quartz, and feldspar. Mica is the platy mineral that exhibits shiny cleavage faces when the rock is viewed closely in a good light. The specimen may contain either muscovite (white mica) or biotite (brown or black mica). The quartz and feldspar grains are white, and about the size of sugar grains.

This rock was formed by metamorphism of a sedimentary rock such as mudstone or sandstone. Other types of schist, with different mineral assemblages, were formed by similar metamorphic processes from other original rock types.

Schist is a relatively abundant rock in portions of those areas of California shown on the map as "Mesozoic-Paleozoic metamorphic and granitic rocks". It has no commercial value.

34. SERPENTINE

Type of rock: metamorphic, fine-grained
Mineral content: antigorite, chrysotile, magnetite, chromite

Serpentine is one of the more colorful types of rock in California. It is a fine-grained metamorphic rock that ranges in color from pale green to greenish black. In many places it has been highly sheared by earth movement, yielding a form aptly called "slickentite" because of the numerous polished, slick, or slippery surfaces in the rock. Such sheared serpentine is characteristically pale green, but in places the slick surfaces are pleasingly mottled with greenish, bluish, and honey colors, and they have a waxy luster. The slip surfaces commonly curve around scattered, rounded blocks of unsheared serpentine that are massive and dark green to greenish black where fractured.

Serpentine is composed predominantly of fine-grained magnesium silicate minerals. In most places, the rock also contains abundant, finely disseminated magnetite and scattered chromite grains.

Most serpentine is derived by metamorphism of peridotite, an unusual igneous rock of high density that is thought to have been intruded from great depths (from the mantle, below the crust of the earth).

Although structurally weak so that it is easily sheared, serpentine is more resistant to weathering than most other rock types. As a result, its outcrop areas are typically revealed by abundant blocks of rock projecting through shallow rust-colored soil.

Serpentine is used to some extent as a decorative stone. However, the most significant economic aspect of this rock is that it is the only host rock for chrysotile asbestos and is the principal host rock for deposits of chromite.

Left. Typical blocky outcrop of serpentine, showing characteristic texture of weathered surfaces.

35. GREENSTONE

Type of rock: metamorphic, fine-grained, massive
Mineral content: chlorite, feldspar

Greenstone is a fine-grained rock derived by metamorphism of certain volcanic rocks, such as basalt, that are relatively rich in iron and magnesium. Under the influence of moderately deep burial and nondirectional (hydrostatic) stresses, the black minerals in the basalt recrystallized to form chlorite, a green micaceous mineral. The resulting metamorphic rock, greenstone, has an overall dull green or dark green color, and is massive. (In regions where directional stresses were present at the time of metamorphism, the same types of volcanic rocks become foliated because of the parallel orientation of the new chlorite flakes. This yielded a dull-green, flaky metamorphic rock known as chlorite schist).

Most of the greenstone in California was derived from basalt that was erupted as submarine lava flows. Such eruptions commonly resulted in excess silica being dissolved in hot sea water, and subsequently precipitated as chert when the water cooled. As a result, greenstone and chert are often found together, and have about the same distribution in California.

Crushed greenstone is used for roofing granules.

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Left. **Greenstone exposure, showing "pillow structure" that has a boulder-like appearance. This structure is characteristic of many of the greenstone outcrops in California, and indicates the lava was erupted under water. Note the hammer at lower left for scale.**

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